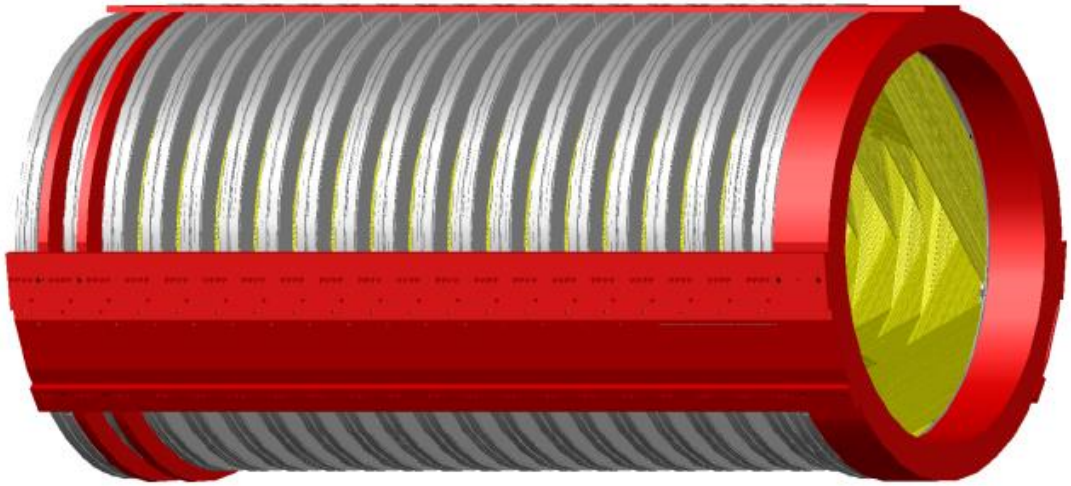

Straw Leak Testing for the Mu2e Tracker

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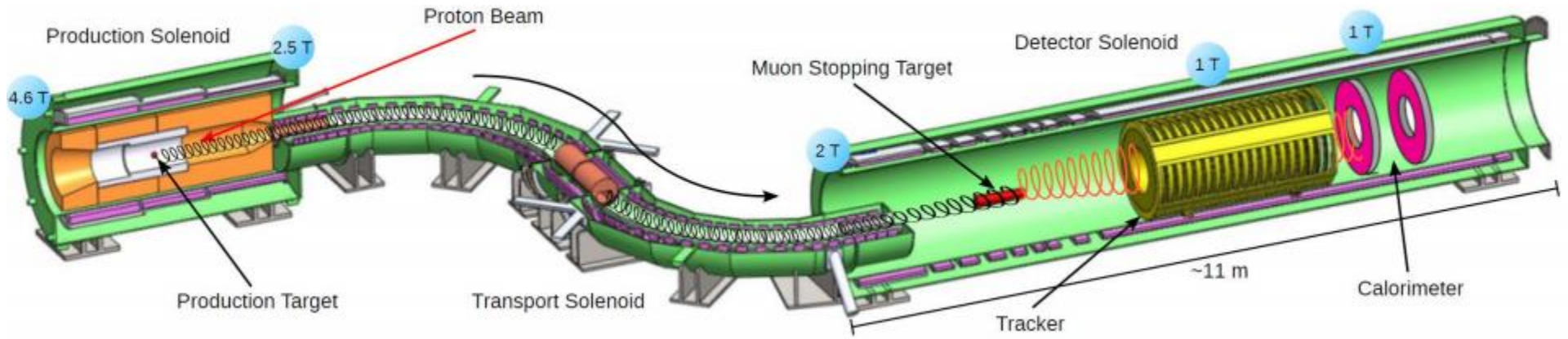
For the Mu2e tracking group

DPF 2015
Aug 5, 2015

Mu2e Design

The Mu2e experiment at Fermilab will search for the neutrinoless conversion of a muon into an electron in the field of an Al nucleus.



As the previous talk by Jim Popp introduced the Mu2e experiment and went into detail on the Tracker design, I will keep the introduction brief.

Mu2e Straws

Physical description:

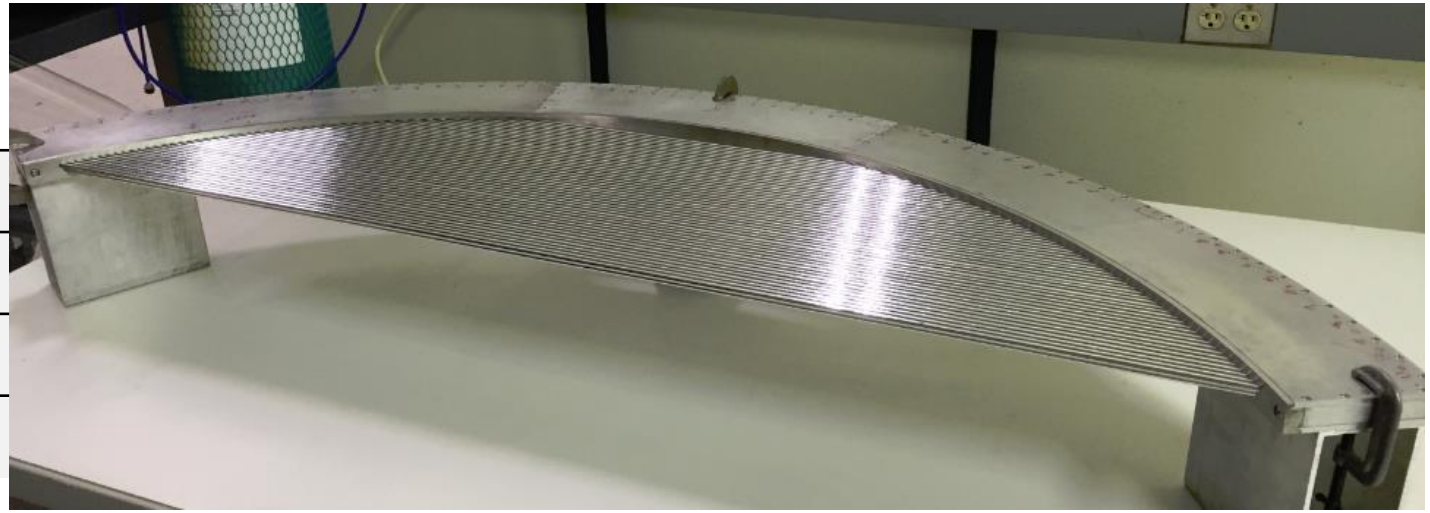
- 15 μm thick Mylar straws
- 5 mm diameter
- Length from 45 to 120 cm
- 500 Å of aluminum on both inside and outside
- An additional 200 Å of gold on the inside

The outside aluminization of the Mylar straws act as additional electrostatic shielding and reduces leak rate of straws.

Mu2e Tracker and Leak Requirements

Tracker Unit	Qty
Stations	18
Planes	36
Panels	216
Straws	20736

Panel Prototype



Throughout the tracker, the straws have a total surface area of over 3 million cm^2.

The straws must hold in the Argon-CO_2 (80:20) gas for the tracker and maintain a 1 atm pressure difference with the vacuum.
In order to maintain a steady state vacuum in the detector solenoid, the entire tracker's leak rate must be below 7 cc/min.

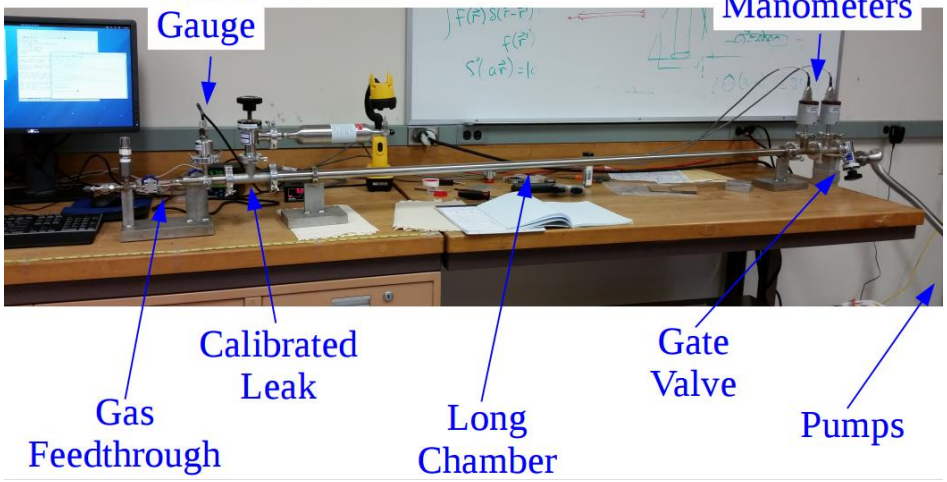
Vacuum Leak Tests

Vacuum leak tests measure the leak rate of straws through prolonged pressure change of the vacuum chamber. The straw is inside a vacuum with 1 atm of Argon-CO_2 (80:20) gas inside the straw.

While a successful method of measurement, the process takes over 24 hours to confidently ensure leak rate is below the 3 x 10^{-4} cc/min for each straw.

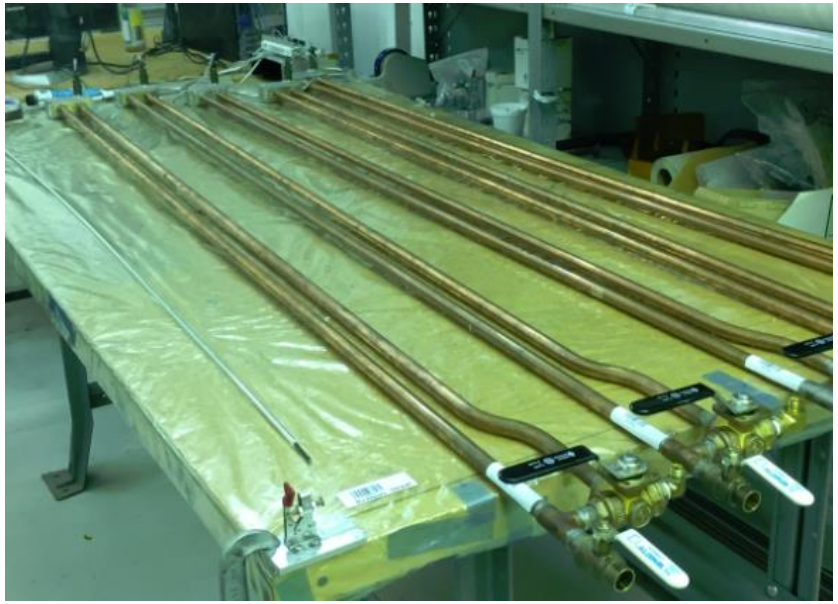
This method is unlikely to be able to test 20,000 straws in a year.

York Vacuum Setup



A New Approach

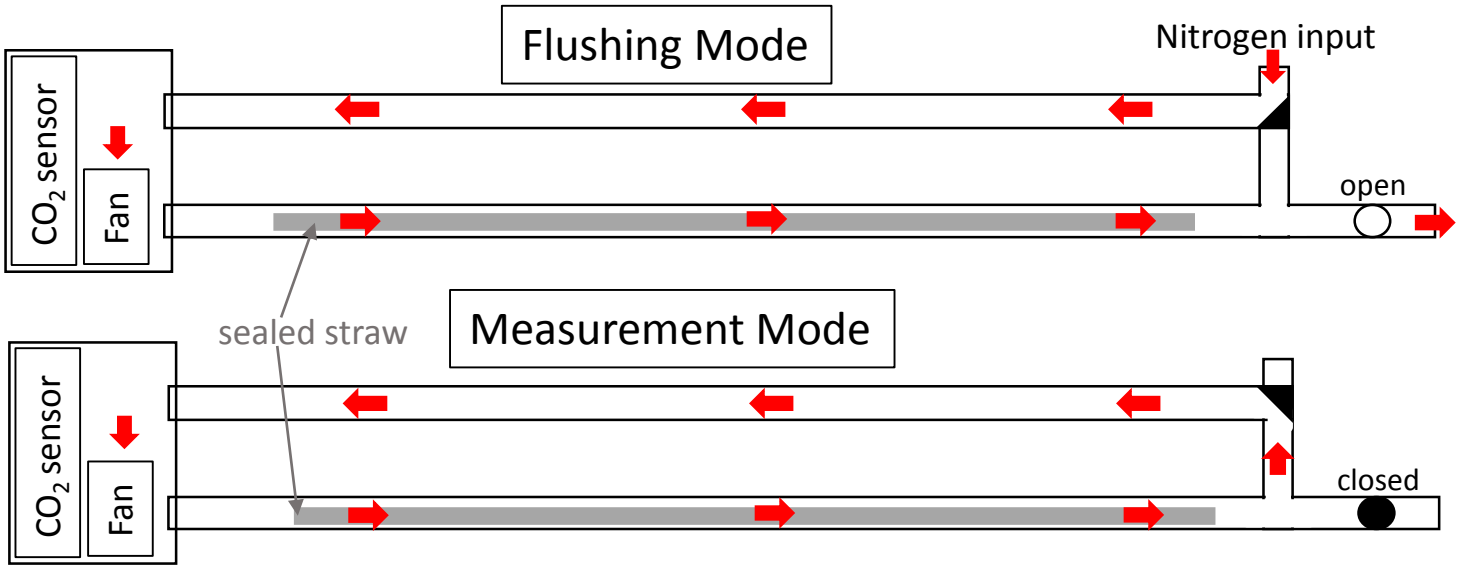
- Studies from Brookhaven[1] and Dupont[2] have shown Mylar to be particularly permeable to CO_2 compared to Argon.
- CO_2 sensors are relatively cheap compared to vacuum equipment, so we can cheaply build many chambers.
- Flushing a chamber with Nitrogen is much faster than pumping down to vacuum and waiting for initial outgassing to settle.



Create a small chamber to house a straw filled with CO_2 and measure the rate at which the CO_2 fills up the chamber.

1:Brookhaven preprint BNL-4892, published in Journal of Vacuum Science and Technology A, vol 12, Issue 4
2: http://usa.dupontteijinfilms.com/informationcenter/downloads/Chemical_Properties.pdf

Leak Test Chamber Design



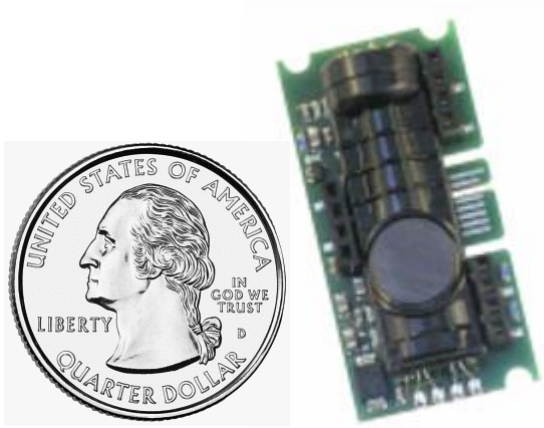
The chamber may operate in two mode:

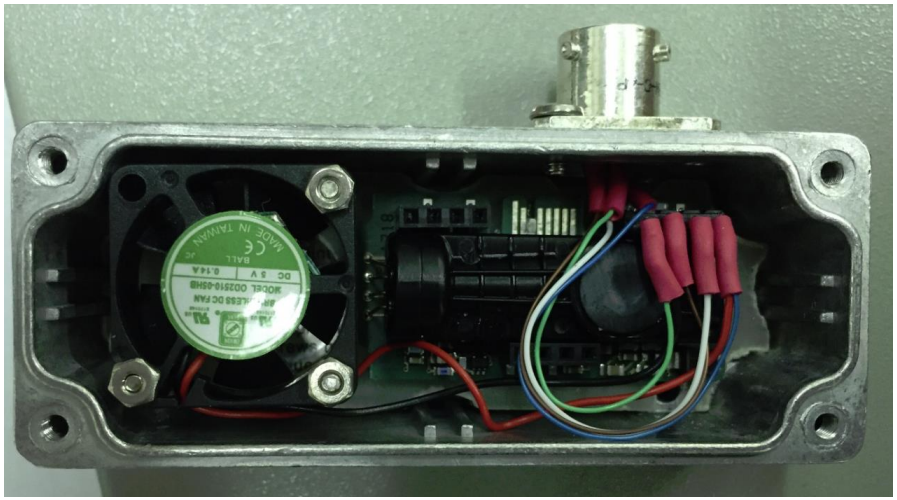
1. Flushing Mode, for flushing the chamber to remove CO_2
2. Measurement Mode, circulate the trapped gases in the chamber for measuring leak rate

Test Chamber parts:

- CO_2 sensor
- Fan
- ½" copper pipe
- 3 way ball valve ◢
- Open/Close ball valve ○

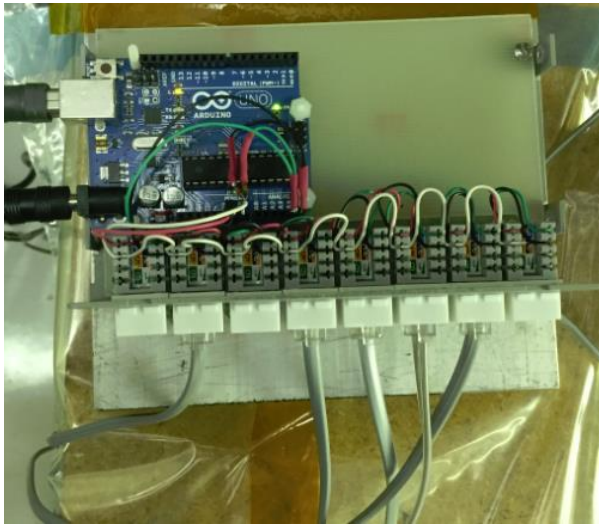
Sensor and Readout





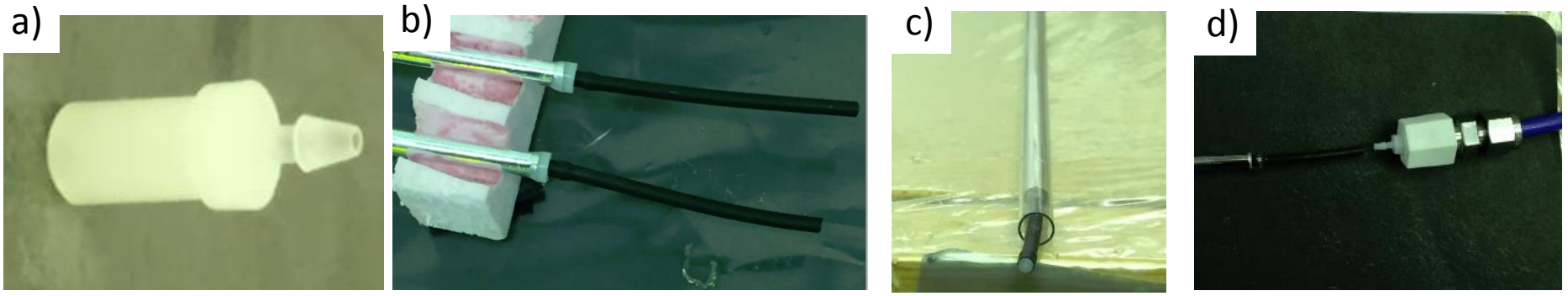
The CO_2 sensors used are EE891 by E+E Elektronik[1]. These give readings every 15 seconds in range from 0 – 2000 PPM with an accuracy of ±50 PPM ±2% .

The CO_2 sensors are read out by a microcontroller. Multiple sensors can be read by a single microcontroller.



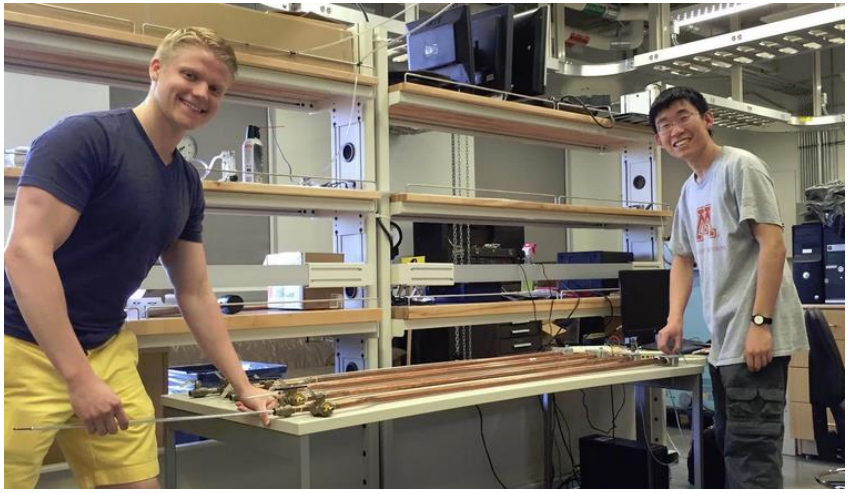
1: http://www.epluse.com/fileadmin/data/product/ee891/datasheet_EE891.pdf

Straw Preparation



a) End pieces have been designed to allow the insertion and trapping of gas in the straw
b) End pieces are epoxied into straws with Viton tubing attached
c) Straws are kept in protective plastic tubes for ease of handling and storage
d) Straws are flushed and then pressurized and sealed to 1 atm above ambient pressure with CO_2

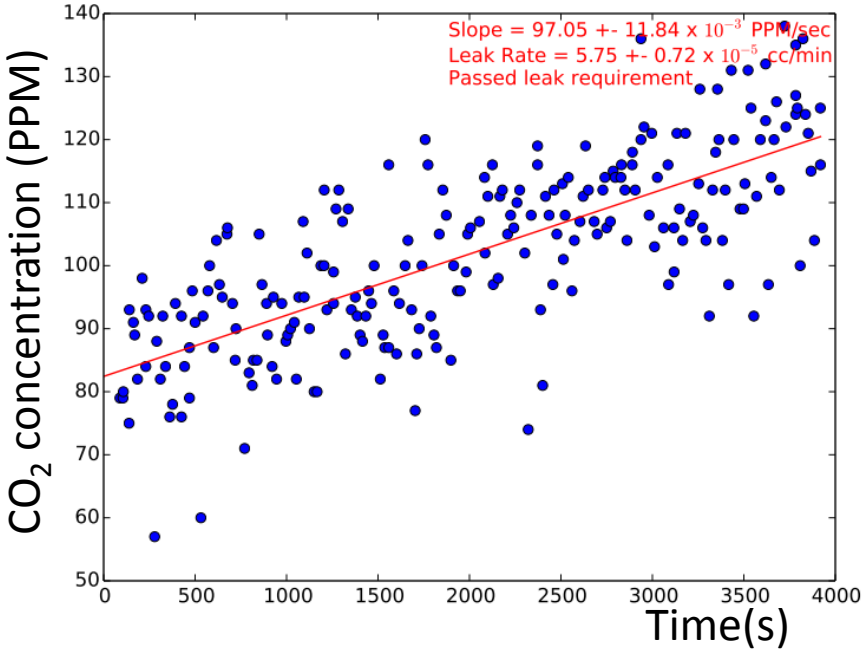
Measurement Procedure



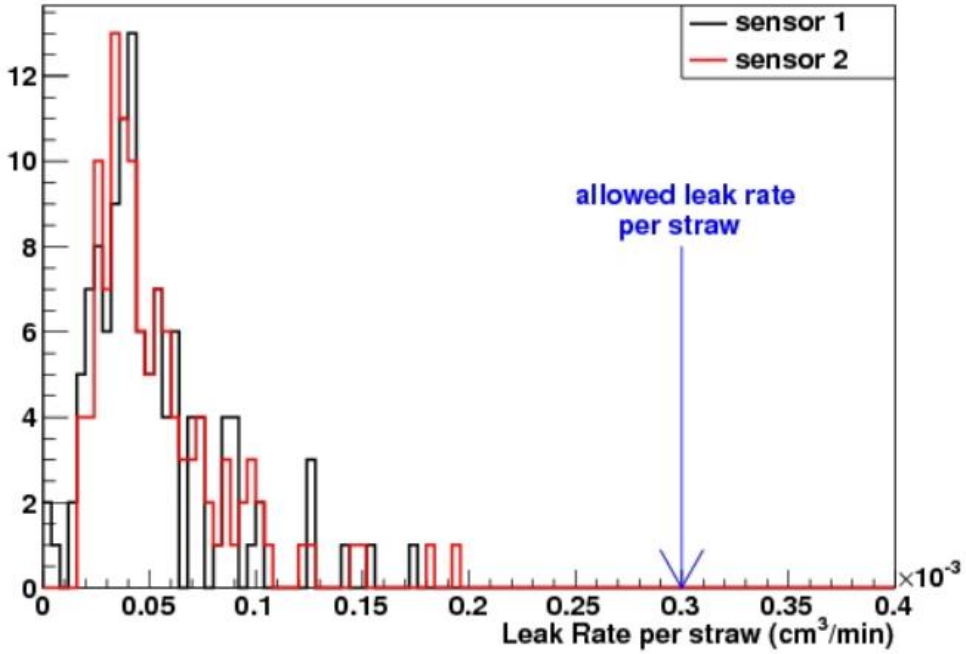
a) Straws are placed into the chamber as the chamber is flushed with Nitrogen
b) Chamber is closed and switched into measurement mode
c) After 1 minute, each sensor reading is used to find the leak rate through a simple linear regression
d) Measurement uncertainty < 1/10 Maximum allowed leak rate in less than 1 hour
e) Straws are then remove and depressurized
f) Chamber is flushed and ready for the next straw

Results

Example Straw Fit



Rice's 119 Straws from Summer 2014



The slope is determined using a simple linear regression.

$$L = aVS$$

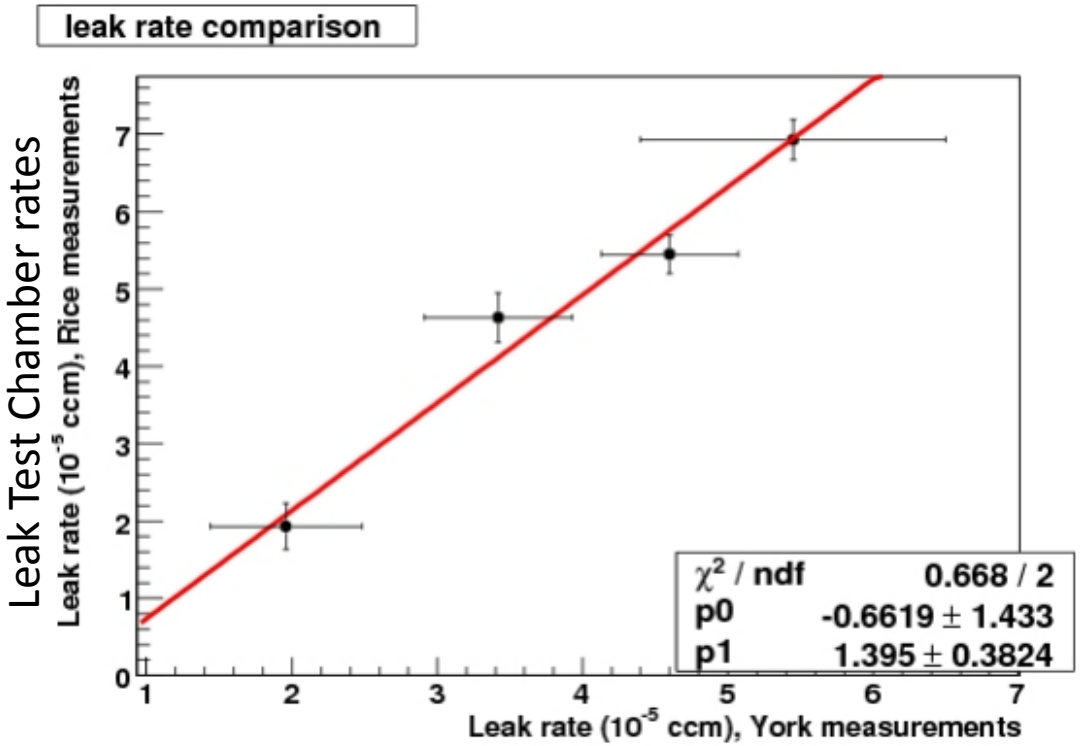
Leak rate(L) for the straw is a factor of slope(S), chamber volume(V), and a correction from using pure CO_2 to Argon-CO_2 mix (a).

The straw's leak rates are well below the allowed range. When following proper procedure no straws failed requirements.

Cross-check with Vacuum method

Specific straws were tested in both setups and the measured leak rates were consistent.

A small fraction of straws will continue to be vacuum tested throughout the production process.



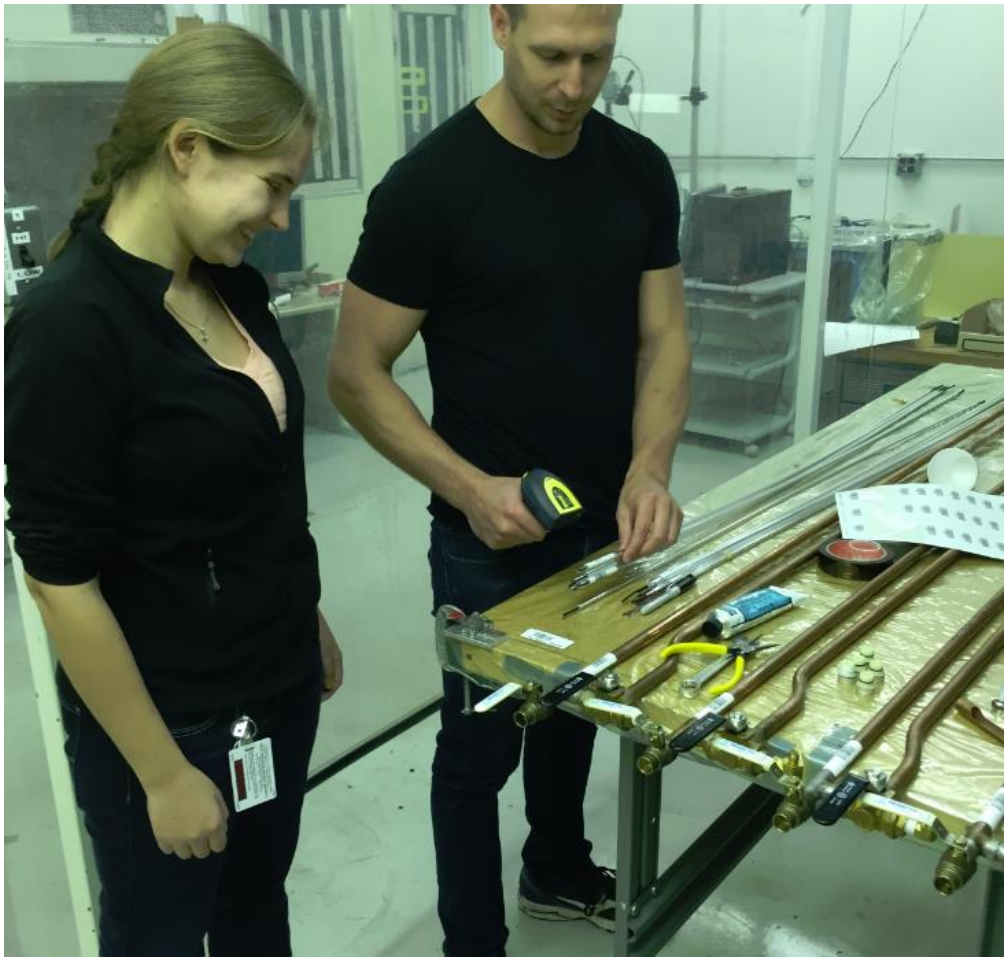
Vacuum Test rates

Mass Production

Over 20,000 straws is a large task.

We currently have 9 operational chambers (5 at Fermilab, 4 at the University of Minnesota). This number should increase as we move into production.

A database is organized to store the leak rate and history of each straw. Straws are given barcodes which are scanned to automate the recording process.



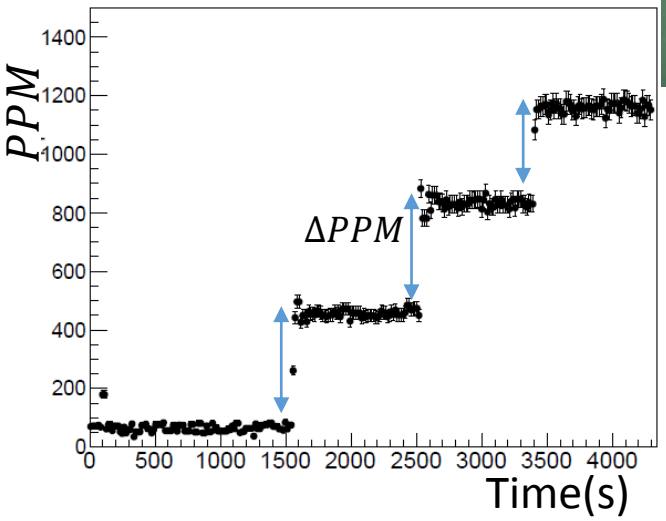
Summary

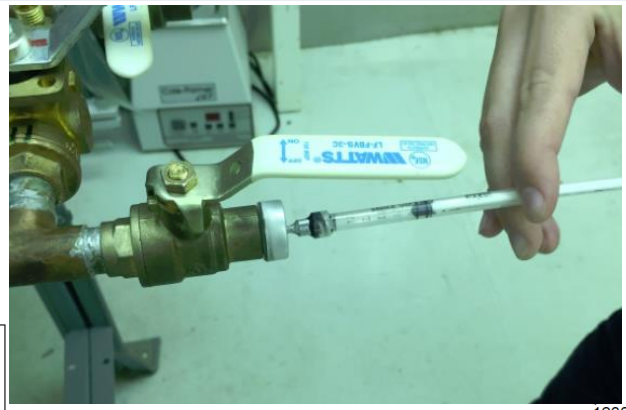
- Making sure the leak rate of the tracker is within specified limits is critical to the Mu2e experiment.
- To this end, every straw will be checked for leaks prior to installation into a panel and every panel will be tested before being put into the tracker.
- We have developed a device and procedure to quickly and accurately measure the leak rates of each straw.
- The Mu2e straws will be tested and ready for assembly by the middle of 2017.

Thank you

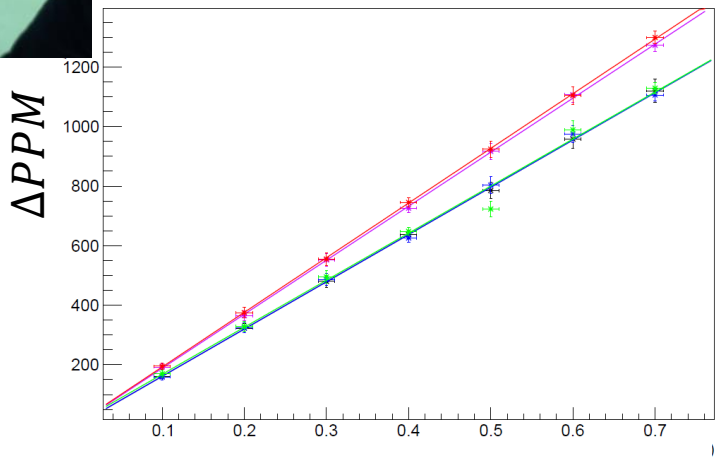
Chamber Volume Calibration

Example of various CO_2 injection measurements





Volume of 5 Chambers of 2 different sizes



The CO_2 sensors measure the level of CO_2 in PPM:

$$PPM = \frac{V_{CO_2}}{V_{chamber}} \times 10^6$$

Measuring ΔPPM vs Injected CO_2 Volume gives us an accurate measurement of the chamber volume to within 4 percent.

Panel Vacuum tests

The final check to ensure no excess leaking of the tracker will come after the panels are fully assembled.

Each panel will be placed into vacuum and measured for total leak rate before being added to the Tracker.